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ON THE REQUIRED SUB DISH AND FEED ARRAY SIZES OF AN OFFSET FEED--ETC(U)
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The limitation of required sizes of a subreflector and a feed array in an offset-feed Gregorian system is investigated. The results are presented as functions of main reflector size and focal length, ratio of focal lengths of main and subreflectors, and range of scan angles. Plots of a wide range of cases for various parameters are presented which can be used as a design guide. From these plots typical designs are selected. It indicates that the

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required subreflector sizes range from 36 percent to 48 percent of the main reflector size while the array size varies from 38 percent to 69 percent when the total scan sector varies from 6 to 12. These required subreflector and array size may not be acceptable.

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CONTENTS

ON THE REQUIRED SUBREFLECTOR AND FEED ARRAY SIZES OF AN OFFSET FEED, ELECTRONIC SCANNING GREGORIAN SYSTEM

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INTRODUCTION

Combining a reflector antenna system with a phased array can achieve economically an electronic scanning beam system with a large aperture. The near-field Cassegrain antenna which utilizes confocal paraboloids and a relatively small planar-array feed was recently shown to have some attractive features as a limited-scan system [1]. In this report the term Cassegrain refers to an arrangement in which the parabolic subreflector is between the phased array and the common focal point. For the Gregorian arrangement, the focal point is between the phased array and the subreflector. Over the limited range of scan afforded, the system combines the high resolution and (to a large degree) the low cost of a reflector antenna with the performance capability of an electronically scanned array.

To achieve good scan range with the near-field Cassegrian system, the subreflector and consequently the blockage ratio must be relatively large. The resulting degradation of the efficiency and sidelobe characteristics is the main disadvantage of this technique. A variation on the basic theme is an offset-feed near-field Gregorian geometry shown schematically in Figure 1. The subreflector is well into the near field of the array and both reflectors are offset sections of confocal, coaxial paraboloids. Dudkovsky [2] proposed this configuration for efficient illumination of a large reflector. Skahill et al [3] investigated the off-axis properties of the system. Fitzgerald [4] evaluated the scanning capabilities of the three-dimensional near-field Gregorian geometry, i.e., circular sections of paraboloids with an analysis based on ray tracing and scalar diffraction theory.

The advantages of the offset-feed geometry as opposed to the circularly symmetric Cassegrain are:

1. Blockage is eliminated; the efficiency and sidelobes are not sacrificed when using the larger subreflector required for increased scan coverage.

2. Spillover, the main cause of scan loss with the Cassegrain feed, is markedly reduced because the array can be positioned very close to an enlarged subreflector. This is the conclusion drawn by Fitzgerald [4].

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This configuration is of interest to the SPACEGUARD system. The affordable electronically scanned system with large aperture and light weight is very attractive. Fitzgerald [4] formulated a procedure to compute the radiation pattern numerically at various scan angles which is exceedingly useful. His results indicate that even at a very large scan angle, the degradation of radiation pattern still seems to be tolerable, making this proposed system very interesting.

In this report an investigation of the required subreflector and feed array sizes is conducted. This investigation allows a wide range of scan angles and various main reflector sizes and focal lengths with a basic requirement that no spill-over is allowed. The results are useful for choosing an appropriate system.

ANALYSIS AND ASSUMPTION

The approach adopted here is to analyze the reflector system as a receiving system . The plane waves incident upon the main reflector will be reflected to the subreflector. Since the subreflector is a confocal paraboloid, the waves reflected from the subreflector will also be planar if the incidence angle is close to the axis. When the incidence angle of the incoming wave increases, the subreflector and the array sizes must be sufficiently large so that the incoming plane wave will fall within the boundary of the subreflector and the feed array. The required subreflector and array sizes are functions of scan angles and the focal lengths of both the main reflector and the subreflector. Since the paraboloids have rotational symmetry, a two dimensional treatment of this problem is adequate. Figure 2 shows the coordinates of this system. The origin is at the focal point. Accordingly, the equations for both the main reflector and the subreflector are respectively:

$$Y_m^2 = 4f_m(X_m+f_m) \tag{1a}$$

$$Y_s^2 = 4f_s(f_s-X_s) \tag{1b}$$

Where Y_m, X_m and Y_s, X_s are points on the main reflector and subreflectors while f_m and f_s are their focal lengths, respectively. The incoming plane wave which tilts at an angle of θ with respect to the normal of the main reflector has a unit vector

$$\hat{a} = \cos\theta\vec{i} + \sin\theta\vec{j},$$

where $\vec{i}$ and $\vec{j}$ are the unit vectors in the x and y directions, respectively. The reflected wave unit vector $\hat{b}$ is

$$\hat{b} = A\vec{i} + B\vec{j} \tag{2}$$

where

$$A = -\cos\theta + 4f_m \frac{2f_m\cos\theta - Y_m\sin\theta}{Y_m^2 + 4f_m^2} \tag{3a}$$

$$B = -\sin\theta - 2Y_m \frac{2f_m\cos\theta - Y_m\sin\theta}{Y_m^2 + 4f_m^2} \quad (3b)$$

This reflected ray will intercept the subreflector at a point whose location is

$$Y_s = 2f_s \left[-\frac{A}{B} \pm \sqrt{\left(\frac{A}{B}\right)^2 + \left(\frac{A}{B}\right)\left(\frac{Y_m}{f_s}\right) + 1 + \frac{X_m}{f_m}} \right]$$
$$X_s = f_s - Y_s^2/4f_s \quad (4a)$$

To ensure that no spill over loss occurred in a scan range from θ_1 to θ_2, the four extreme points must be all fall within the boundary of the subreflector. These four points are the intercepting points of the rays reflected from the main reflector at the two extreme points at each of the two extreme scan angles. This determines the required size of the sub reflector. The reflected rays from these four points on the subreflector must fall within the boundary of the feed array. This is depicted in Figure 2, where P_1, P_2, P_3 and P_4 are the intercepting points of the rays reflected from the edges of the main reflector at scan angles θ_1 and θ_2. The lines ℓ_1, ℓ_2, ℓ_3 and ℓ_4 are the reflected rays from points P_1, P_2, P_3 and P_4, respectively.

The resulting sizes of the subreflector and array are functions of the scan angles, main reflector size and the focal lengths of both the main reflector and the subreflector. Some computed results are presented in the next section.

REQUIRED SUBREFLECTOR SIZE

The ratio of the subreflector to the main reflector size is presented as a function of the main reflector focal length. A family of such curves is plotted. The main reflector size is used as the parameter of this family of curves. The main reflector diameter is normalized to unity. Hence half the reflector has a size of .5. In this study, it is assumed that a portion of the upper half of the main reflector is used in order to reduce the blockage problem. The limits of the main reflector are defined by R_1 ($y = .5$) and $R(X_m, Y_m)$, and the reflector size is given by $R_m = .5 - Y_m$. Figure 3a shows such a plot for a scan angle from -3 to 3 degrees. The ratio of the focal length of the subreflector to the focal length of the main dish is equal to 2. The cross signs on each curve represent the cases for which blockage occurs. For example, when the main reflector has a normalized size of .5, portions of the incoming plane wave at -3 degrees which would reach the lower portion of the reflector are blocked by the subreflector. However, as Y_m increases, this blockage disappears. Figure 3b shows a similar case except that the focal length ratio of main reflector to subreflector is 4. From these two figures one may conclude the following:

(a) As the main reflector focal length increases the ratio of subreflector to main reflector size increases.

(b) As Y_m (R_m) increases, the ratio of subreflector to main reflector increases.

(c) When the ratio of the focal length of the main reflector and the subreflector increases, for a similar main reflector focal length and size, the required subreflector size decreases.

(d) When the focal length of the main reflector becomes small (less than .3), the solution is unstable.

Figure 4 shows the case of a scan range from -4 to 4 degrees with a ratio of main reflector focal length to subreflector focal length of 3. Figures 5a, 5b and 5c show the cases of a scan angle from -2 to 6 degrees at focal length ratios (main reflector to subreflector) of 3, 4 and 5. Figures 6a and 6b are for the cases of scan angle of -2 to 8 degrees and at focal length ratios of 4 and 5. Similar cases are shown in Figures 7a and 7b for scan angles as large as -4 to 8 degrees. All these figures exhibit a similar characteristic feature. The required subreflector size varies from one-third to equal to or greater than the main reflector.

REQUIRED ARRAY SIZE

Figures 8a and 8b present computed data on the ratio of the required array size to the main reflector size as a function of the main dish focal length for a case of scan range from -3 to 3 degrees. Again the normalized main reflector size is used as a parameter for this family of curves. The following characteristics are evident from these plots:

(a) The ratio of the required array size to the main reflector size decreases as the main focal length increases.

(b) An increase in Y_m (R_m) leads to an increase in the ratio of array size to main reflector size.

(c) Increasing the focal length ratio of the main and subreflectors reduces the ratio of array size to main reflector.

Figures 9 through 12 show various scan angle ranges and focal length ratios. However, the general characteristics are similar to those of Figures 8a and 8b.

From these plots, typical designs having both minimum subreflector and array size free of blockage are listed in the following table:

Table 1

Scan Range	Focal Length	Focal Length Ratio	Subreflector Size	Array Size
-3° to 3°	.3	3	.36	.38
-2° to 6°	.3	5	.35	.41
-4° to 8°	.32	4	.48	.69

It is evident from this table that the required subreflector and array sizes are not small. This may not be acceptable for certain systems. For example, at a scan range of 6 degrees, this system requires a subreflector and array sizes of an area of 15 percent of the main array. For a scan range of 12 degrees required subreflector is 23 percent and the array is 48 percent. Furthermore, the required array in general is larger than the subreflector size.

CONCLUSION

In this report the required subreflector and feed array sizes in an offset-feed Gregorian system are investigated. It is found that these subreflector and array sizes are functions of main reflector focal length, main reflector size, ratio of main and subreflector focal lengths, and the scan angle range. The criterion of determination of such sizes is based on the requirement that a parallel plane wave reflected from the main reflector must fall within the boundaries of both the subreflector and the feed array. A large number of cases are presented which may be used as a design guide.

Some selected typical designs for minimizing both subreflector and array are listed. It indicates that the required reflector sizes range from 36 percent to 48 percent of the main reflector size while the array sizes range from 38 percent to 69 percent when the scan sector varies from 6 degrees to 12 degrees. This required subreflector and array size may not be acceptable.

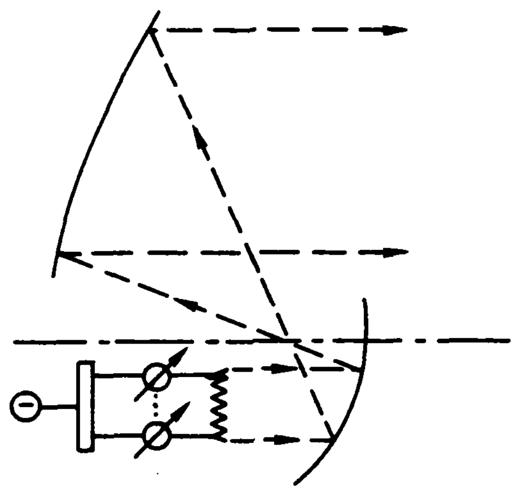


Fig. 1 - Offset-feed Gregorian geometry

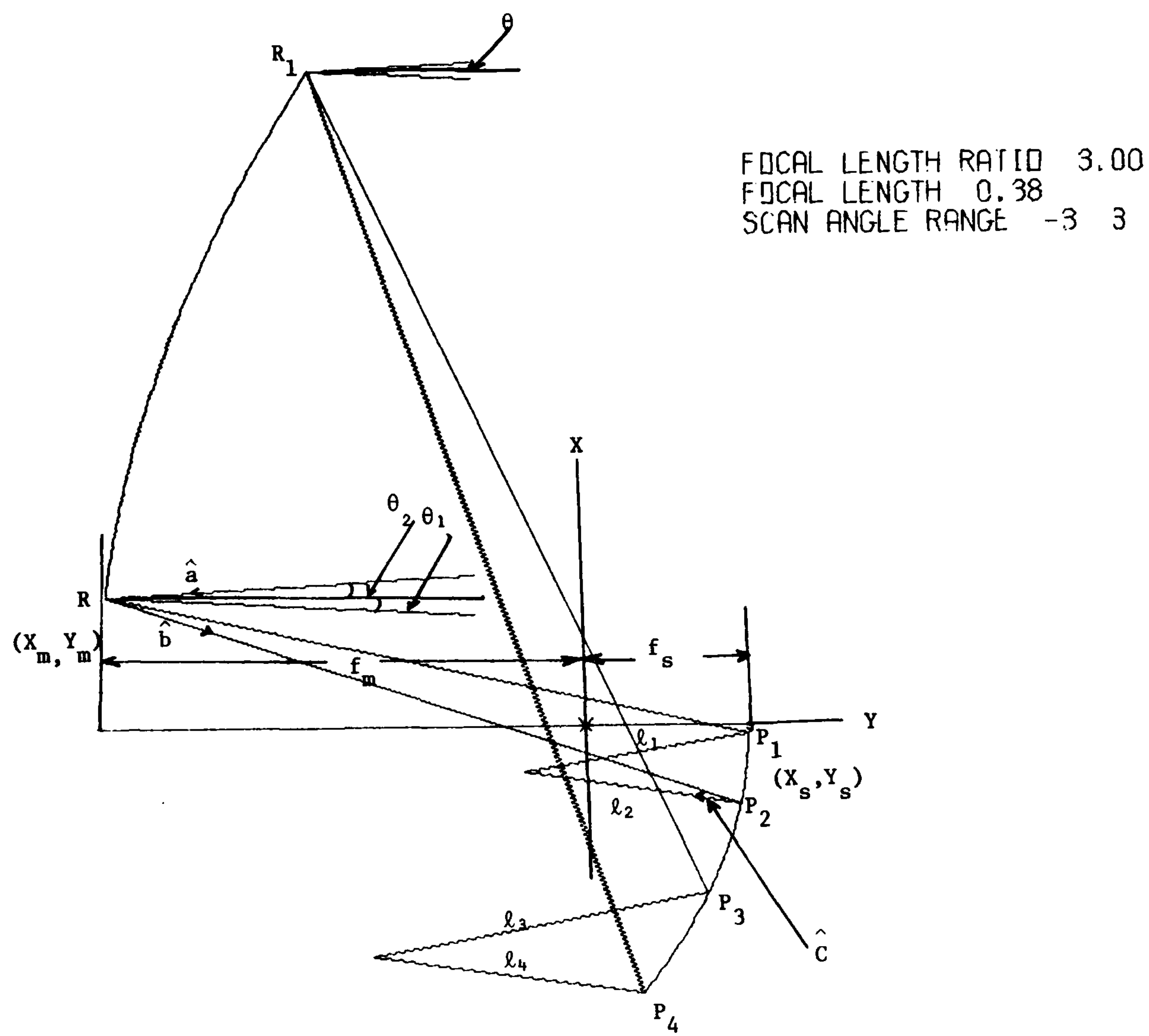


Fig. 2 - Coordinate of an offset-feed Gregorian system

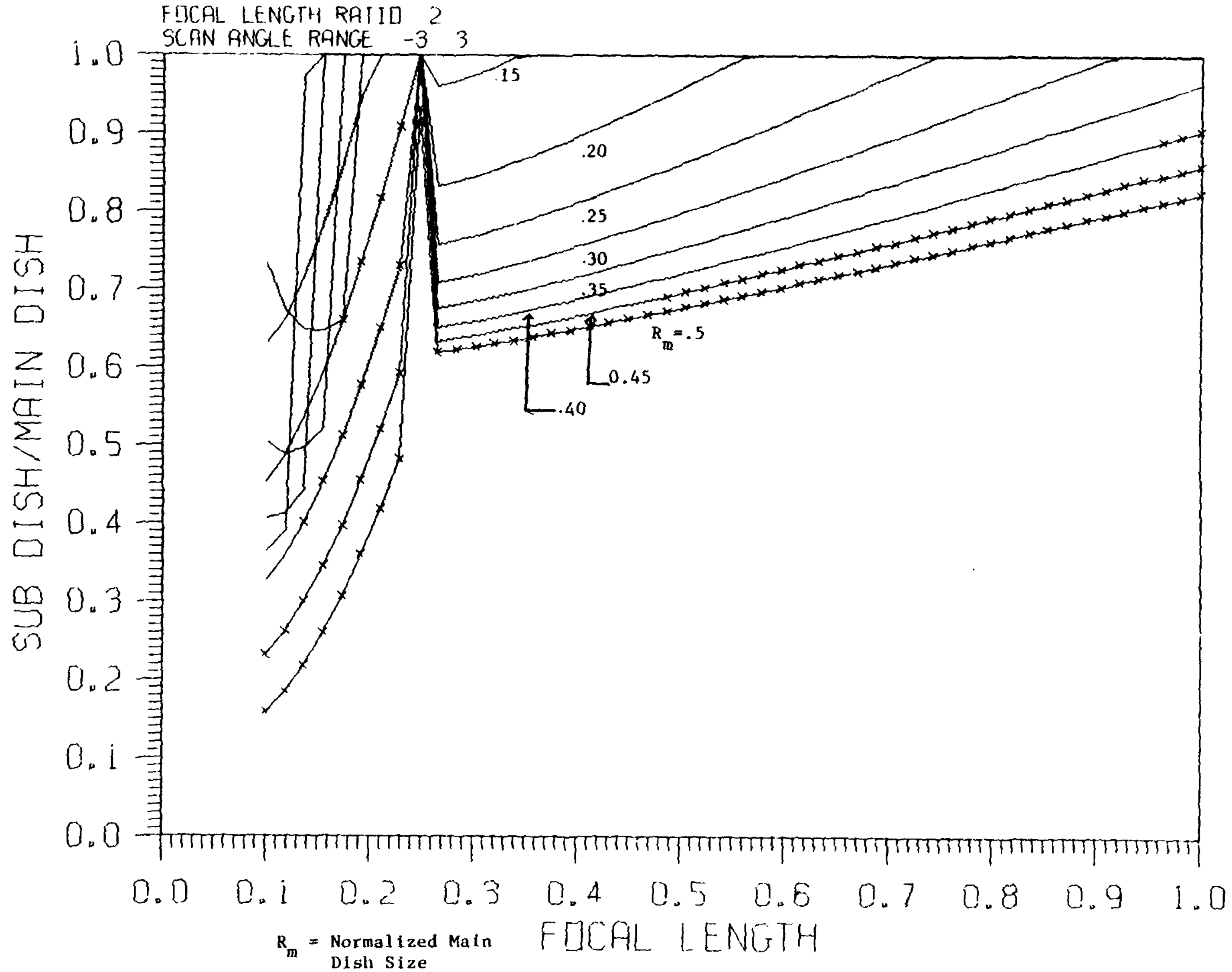


Fig. 3a - Ratio of sub dish to main dish size vs. main dish focal length

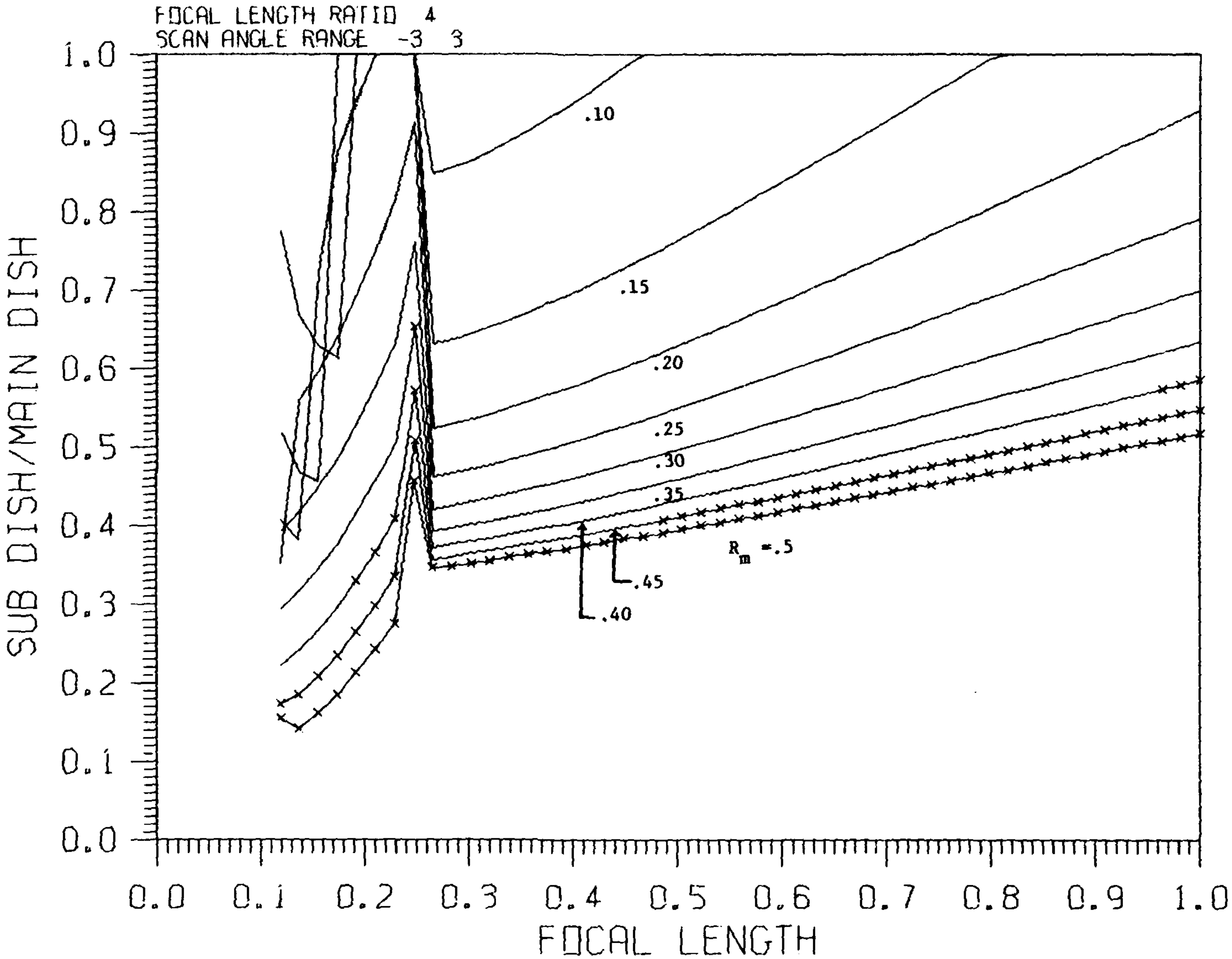
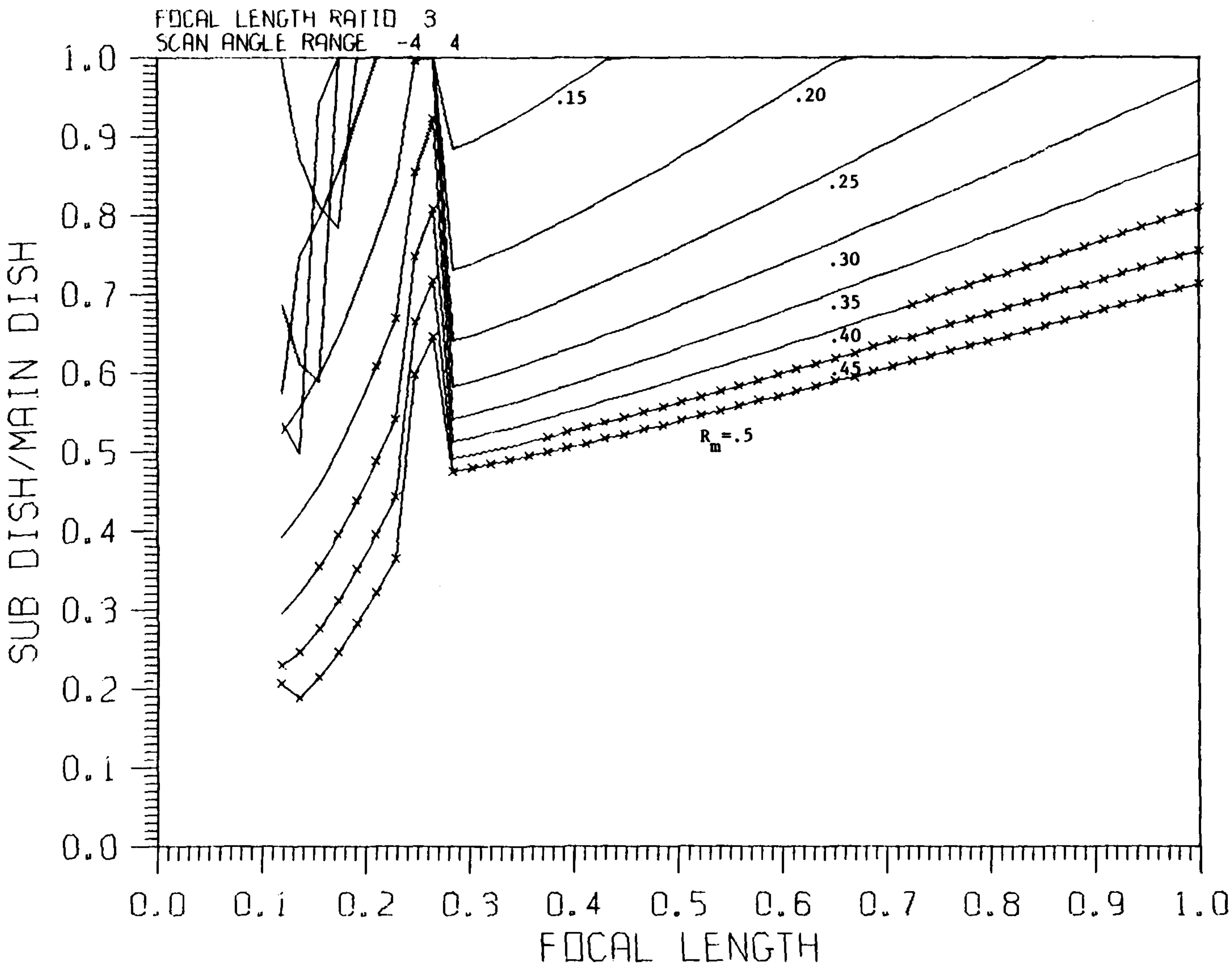


Fig. 3b - Ratio of sub dish to main dish size vs. main dish focal length, R_m = normalized main dish size



R_m = Normalized Main Dish Size

Fig. 4 - Ratio of sub dish to main dish vs. main dish focal length

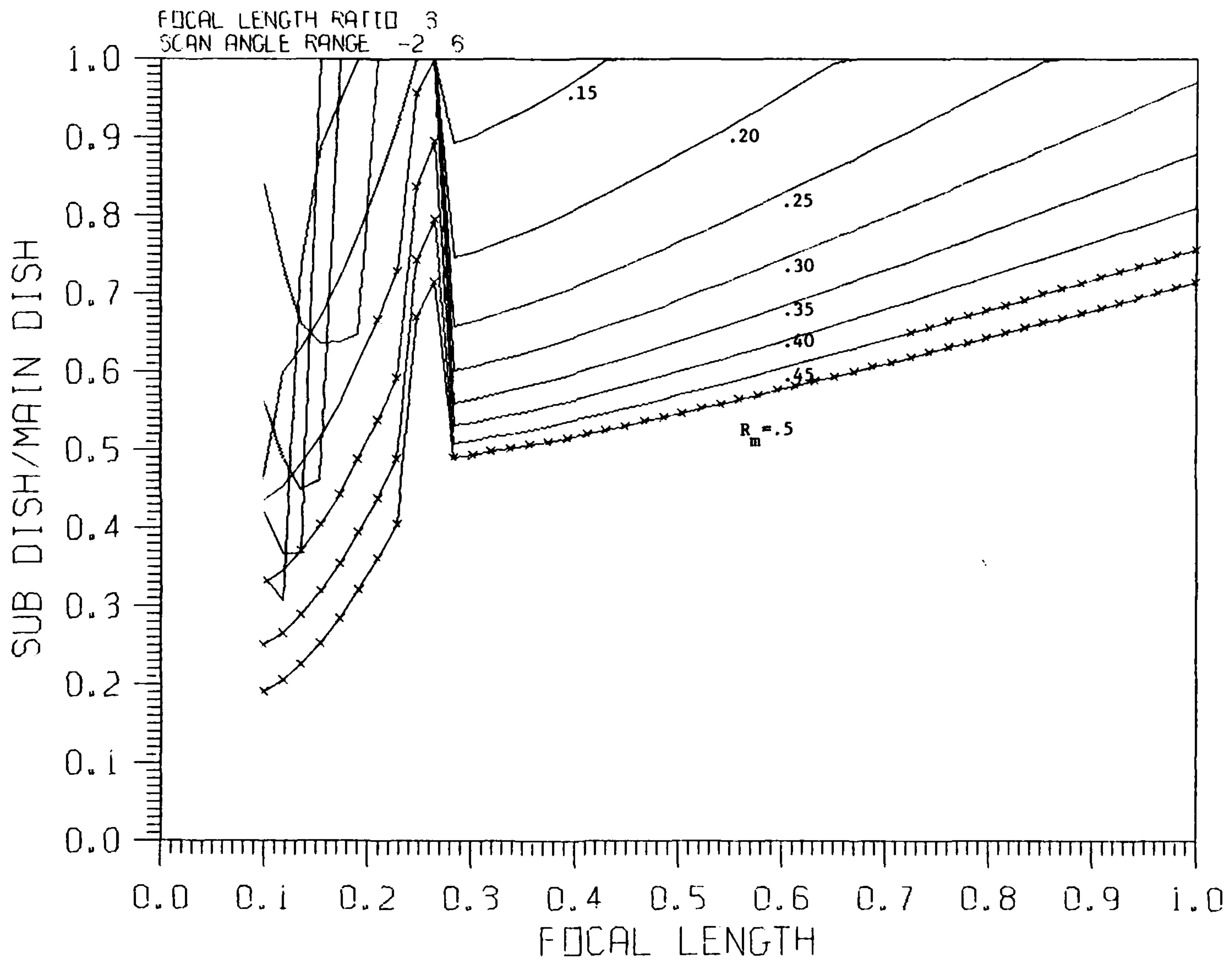


Fig. 5a - Ratio of sub dish to main dish vs. main dish focal length R_m = noramlized main dish size

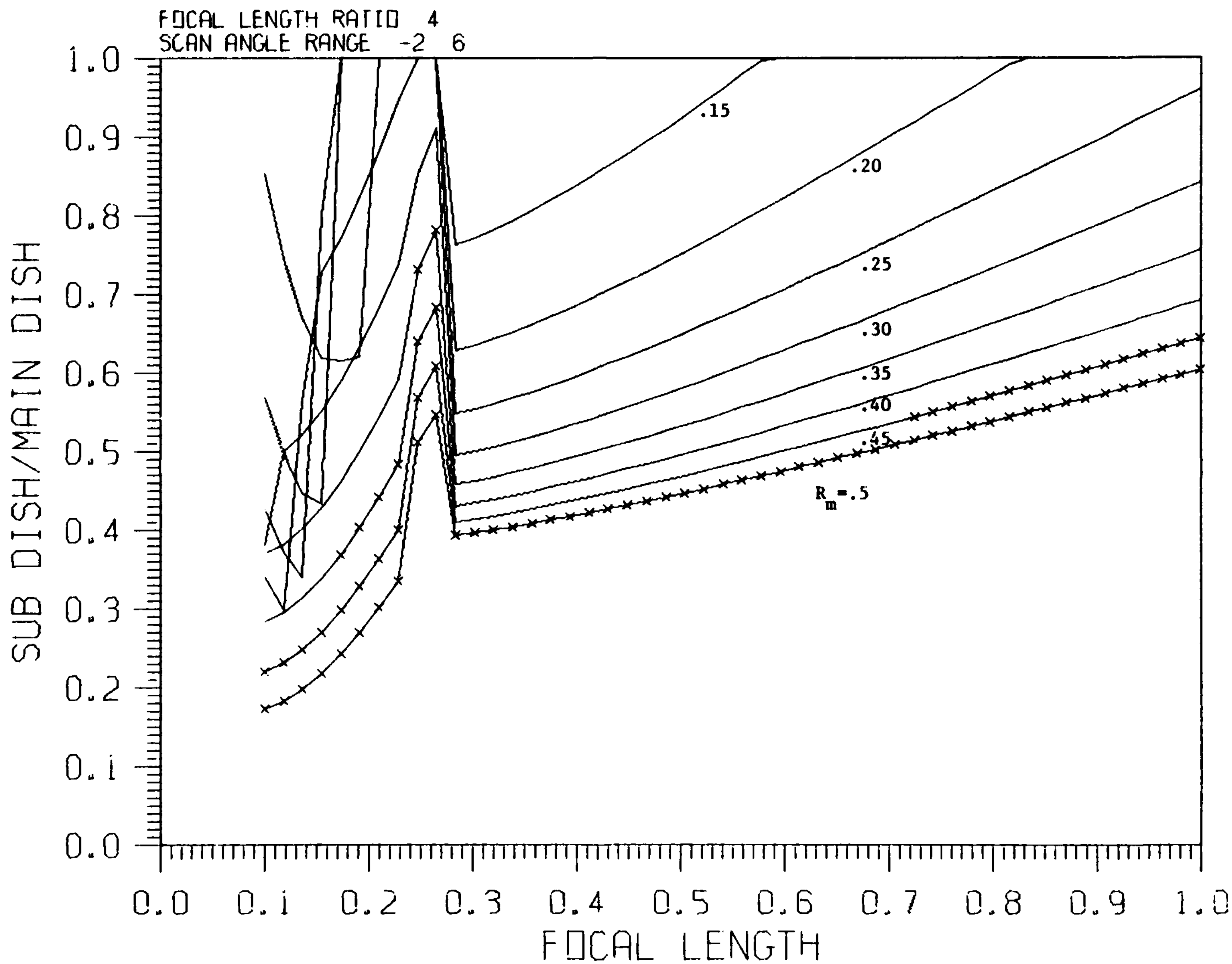


Fig. 5b - Ratio of sub dish to main dish vs. main dish focal length R_m = normalized main dish size

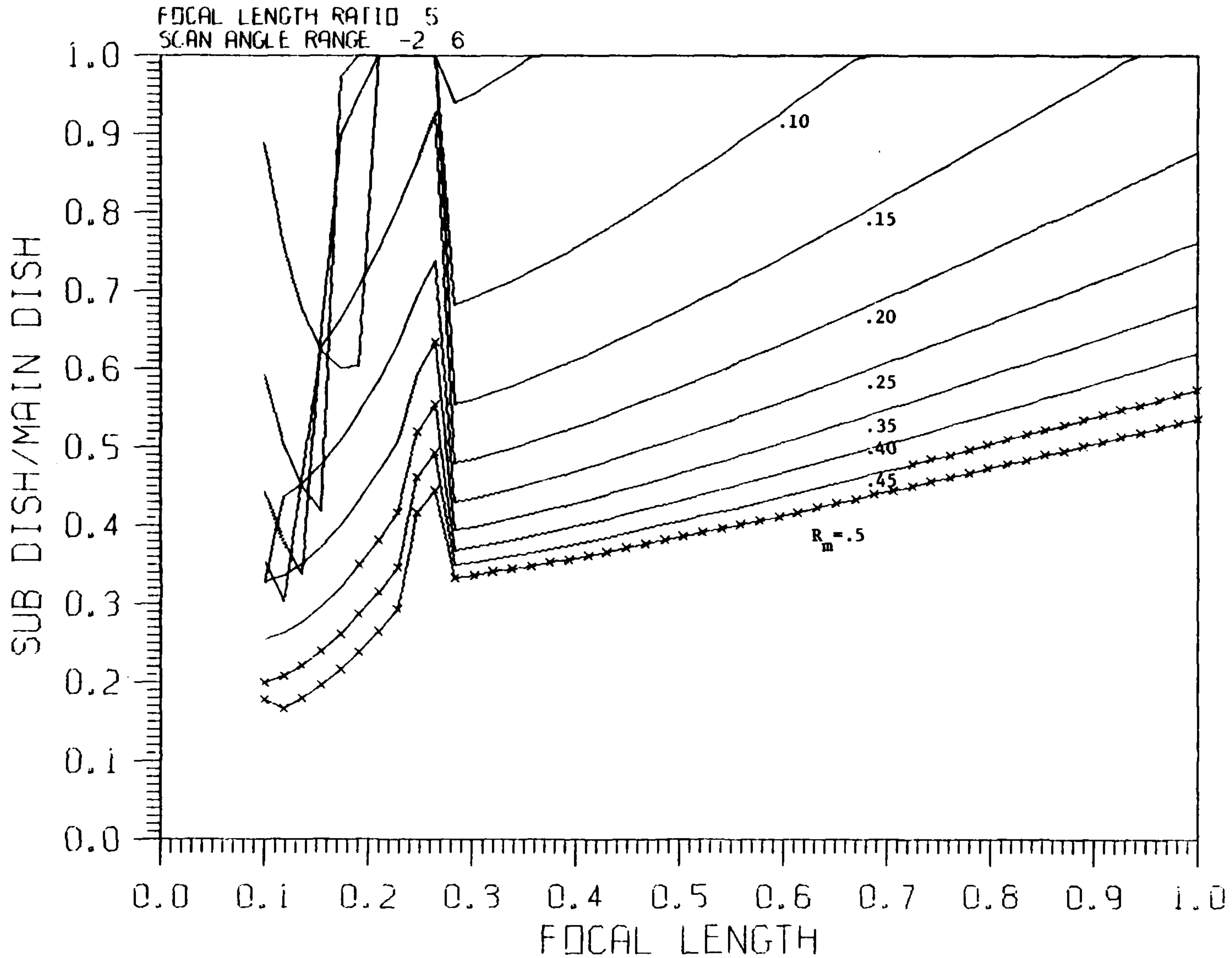


Fig. 5c - Ratio of sub dish to main dish vs. main dish focal length R_m = normalized main dish size

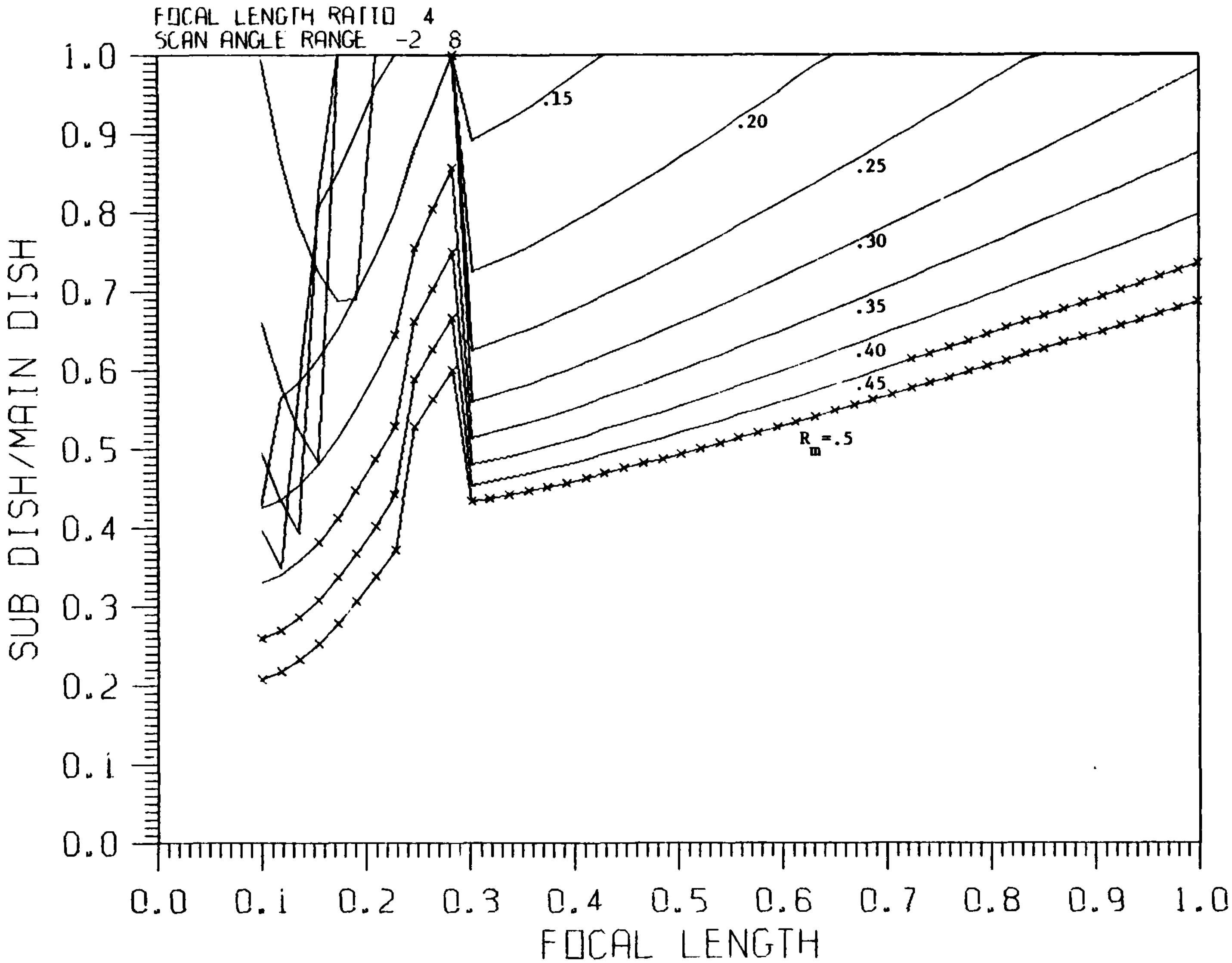


Fig. 6a - Ratio of sub dish to main dish vs. main dish focal length R_m = normalized main dish size

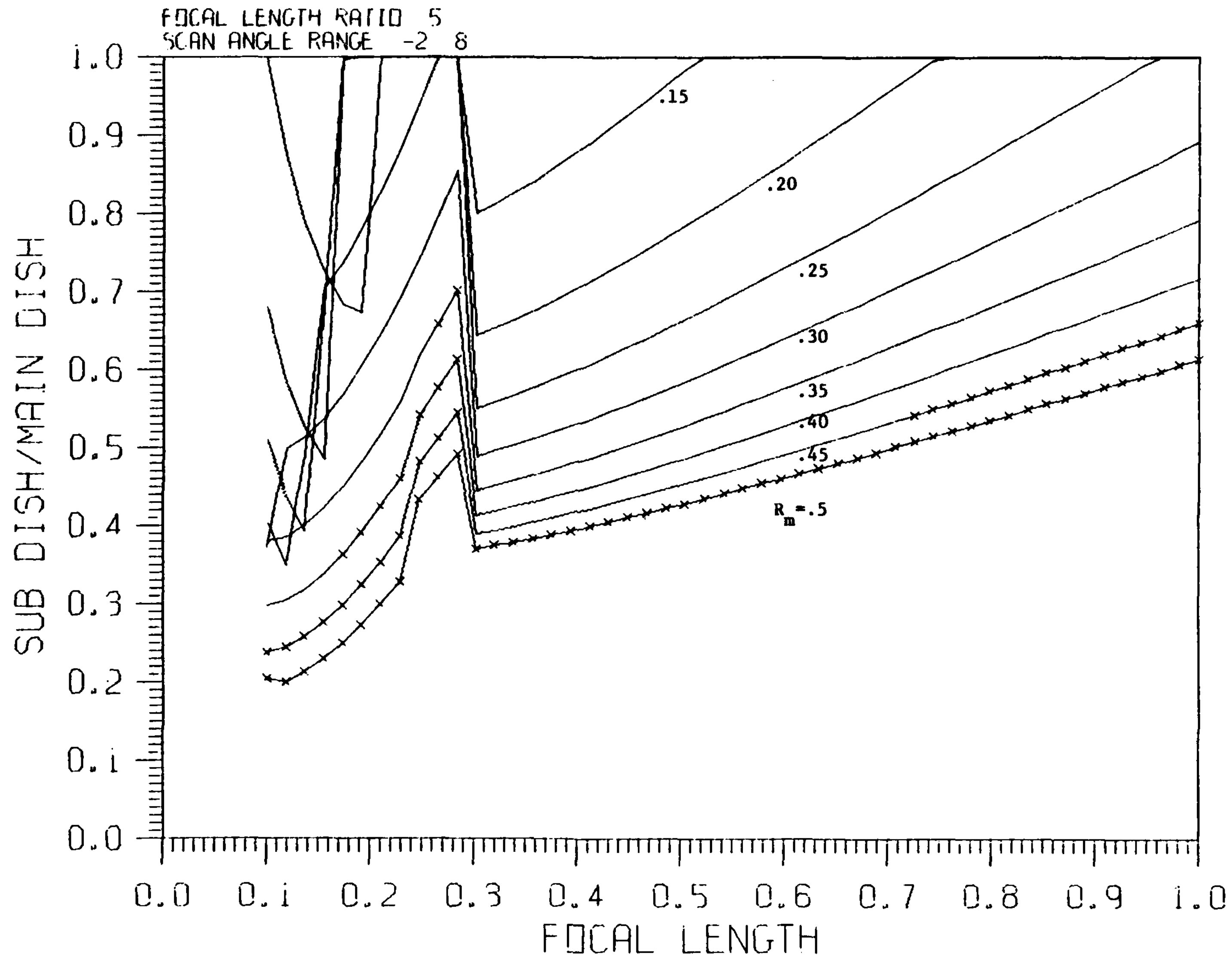


Fig. 6b - Ratio of sub dish to main dish vs. main dish focal length R_m = normalized main dish size

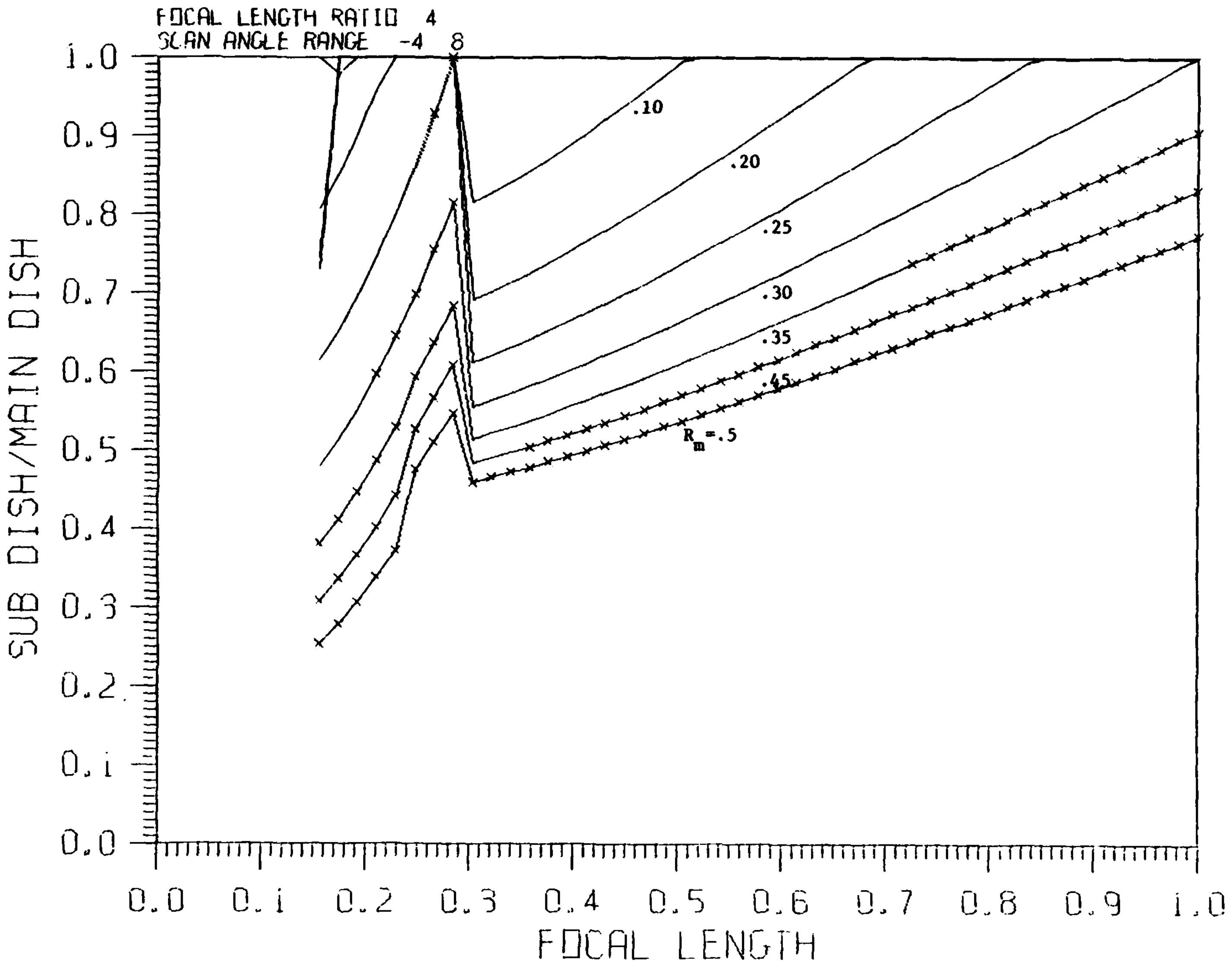


Fig. 7a - Ratio of sub dish to main dish vs. main dish focal length R_m = normalized main dish size

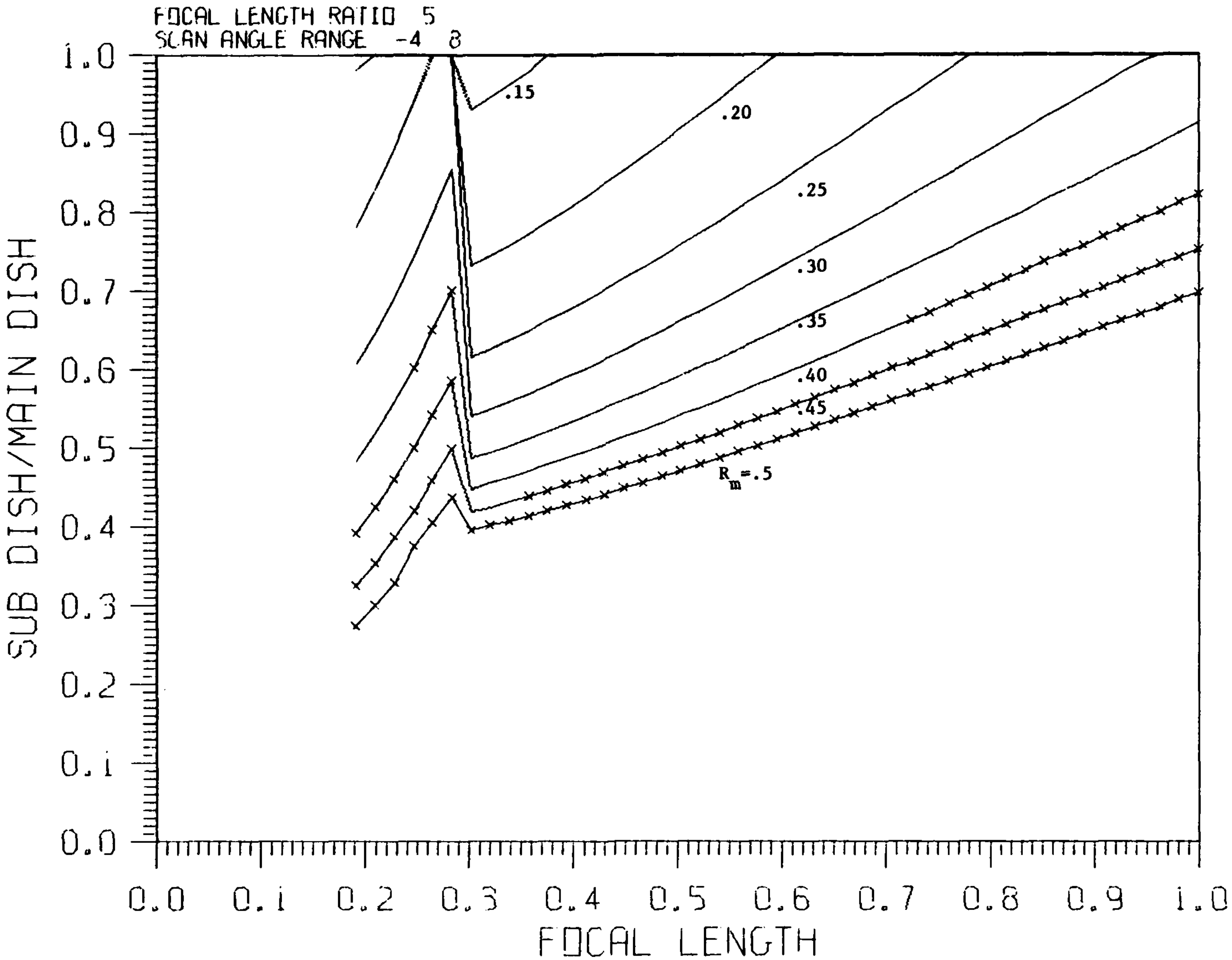


Fig. 7b - Ratio of sub dish to main dish vs. main dish focal length R_m = normalized main dish size

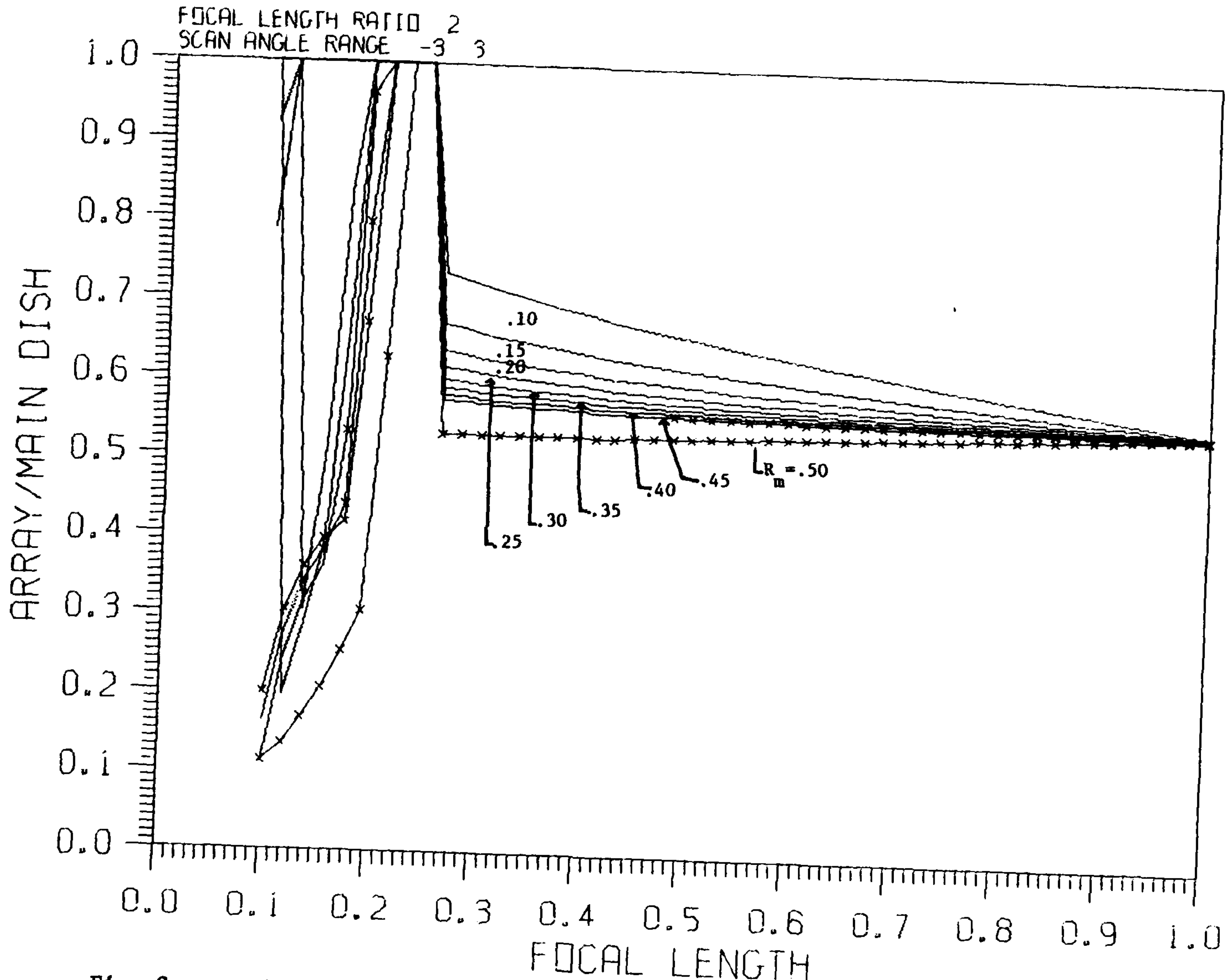


Fig. 8a - Ratio of required array size to main dish vs. main dish focal length
R_m = normalized main dish size

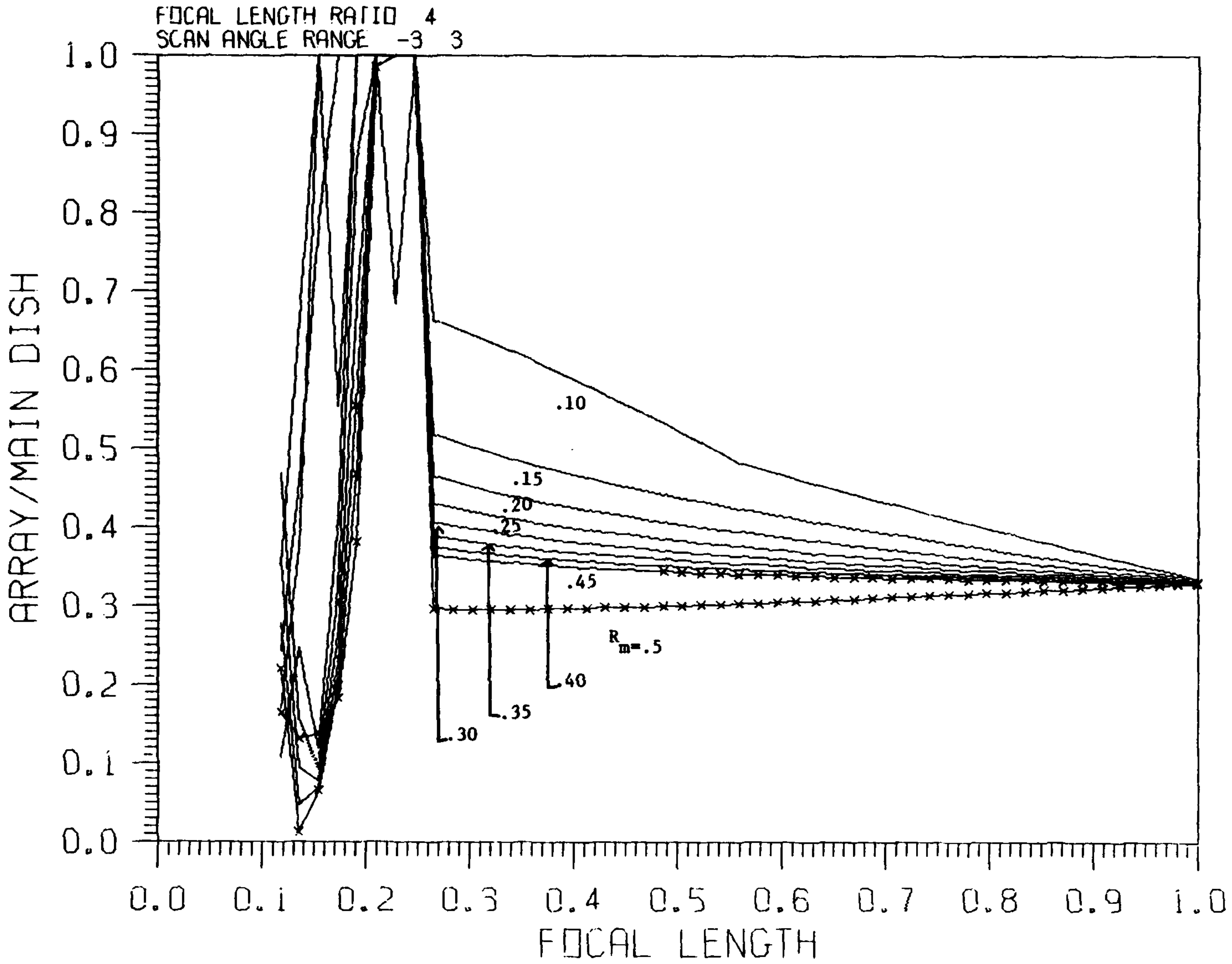


Fig. 8b - Ratio of required array size to main dish vs. main dish focal length
R_m = normalized main dish size

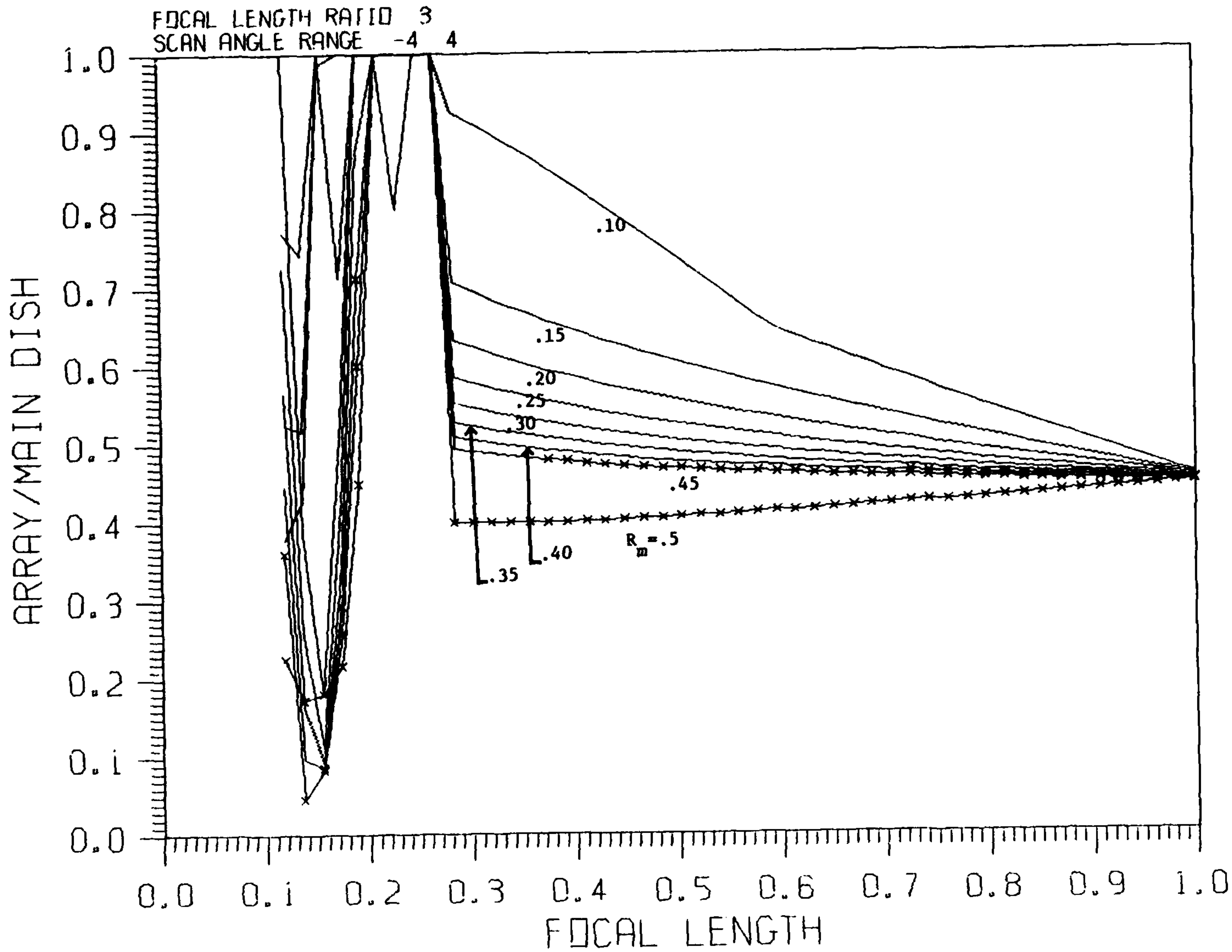


Fig. 9 - Ratio of required array size to main dish vs. main dish focal length
R_m = normalized main dish size

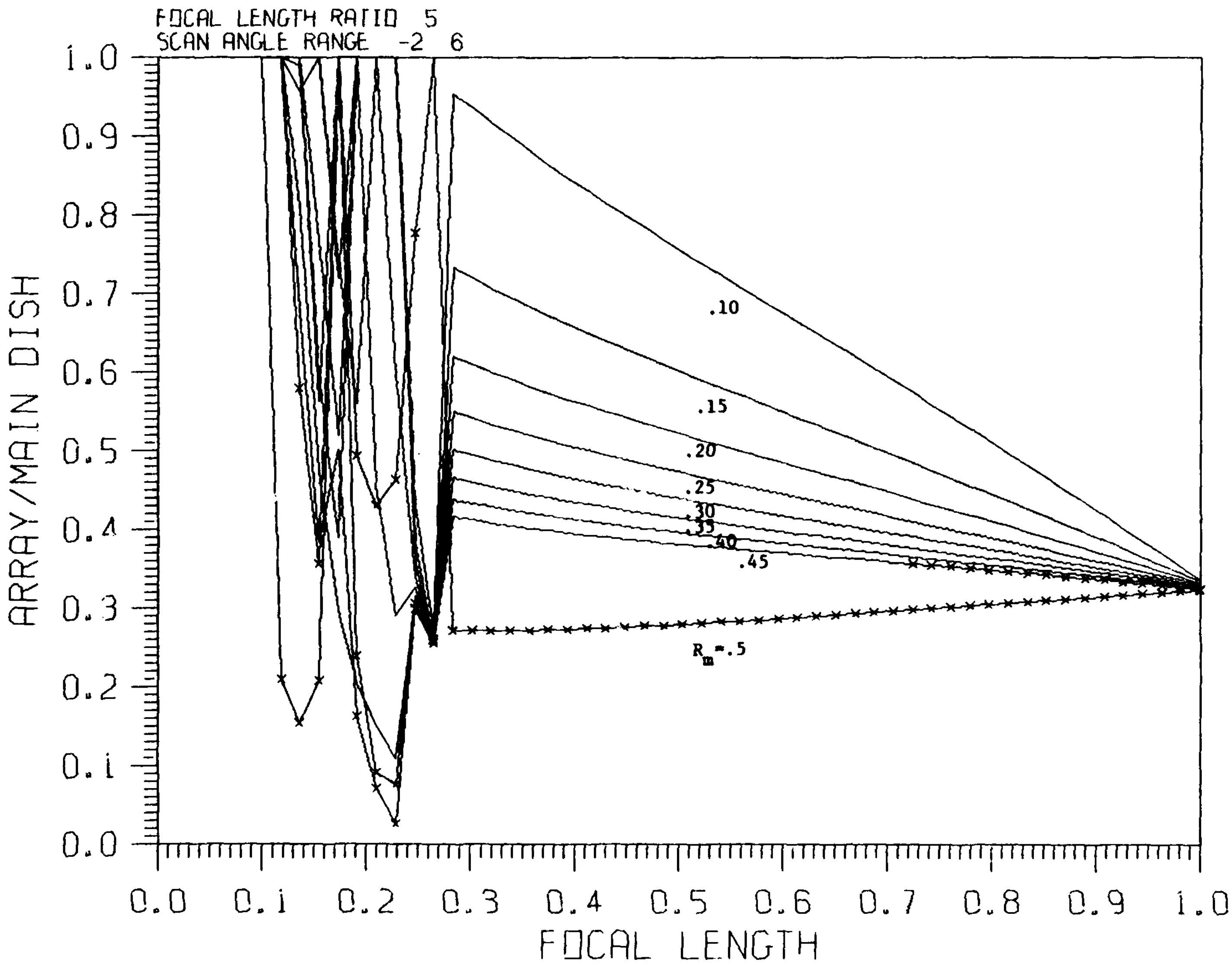


Fig. 10a - Ratio of required array size to main dish vs. main dish focal length
R_m = normalized main dish size

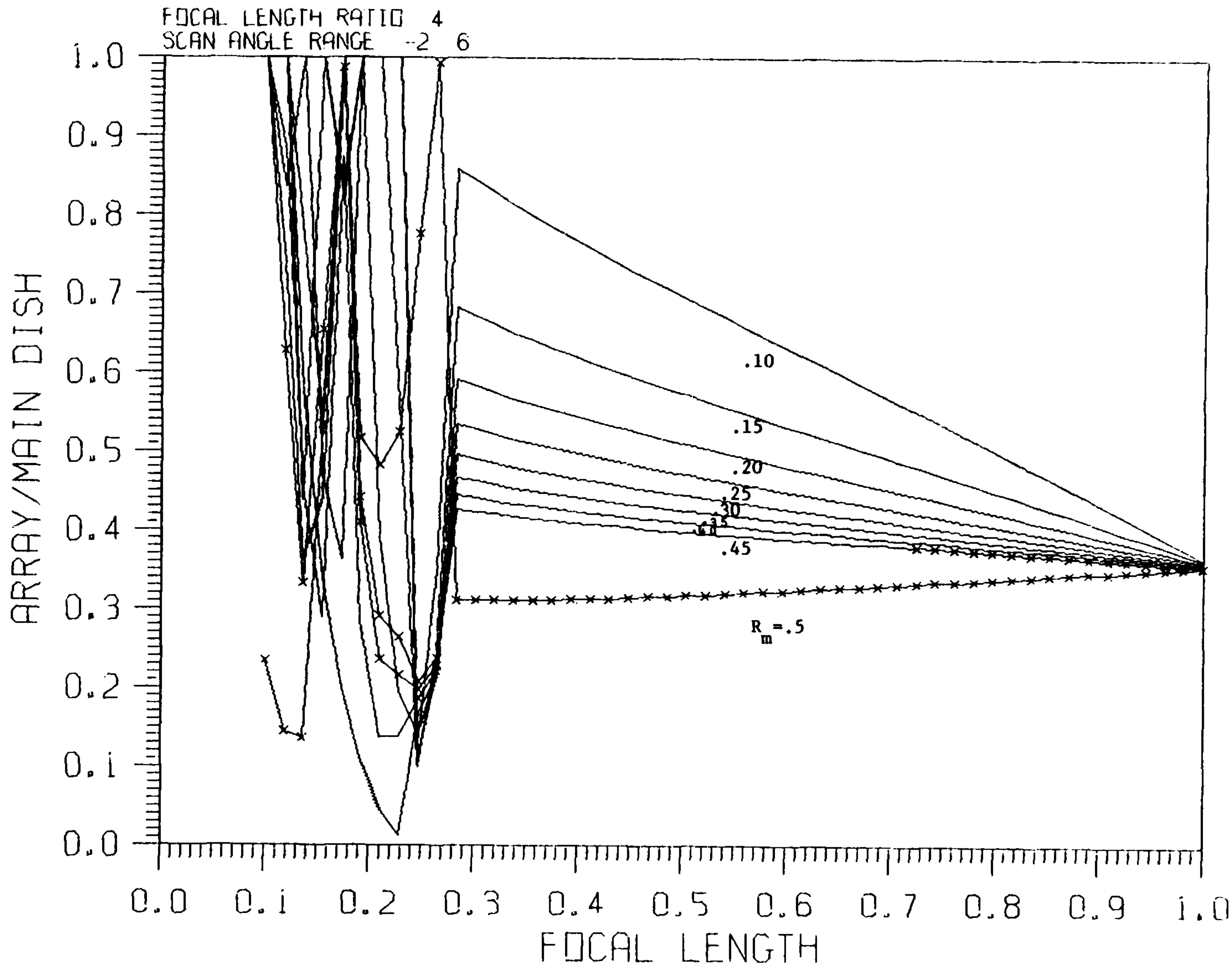


Fig. 10b - Ratio of required array size to main dish vs. main dish focal length
R_m = normalized main dish size

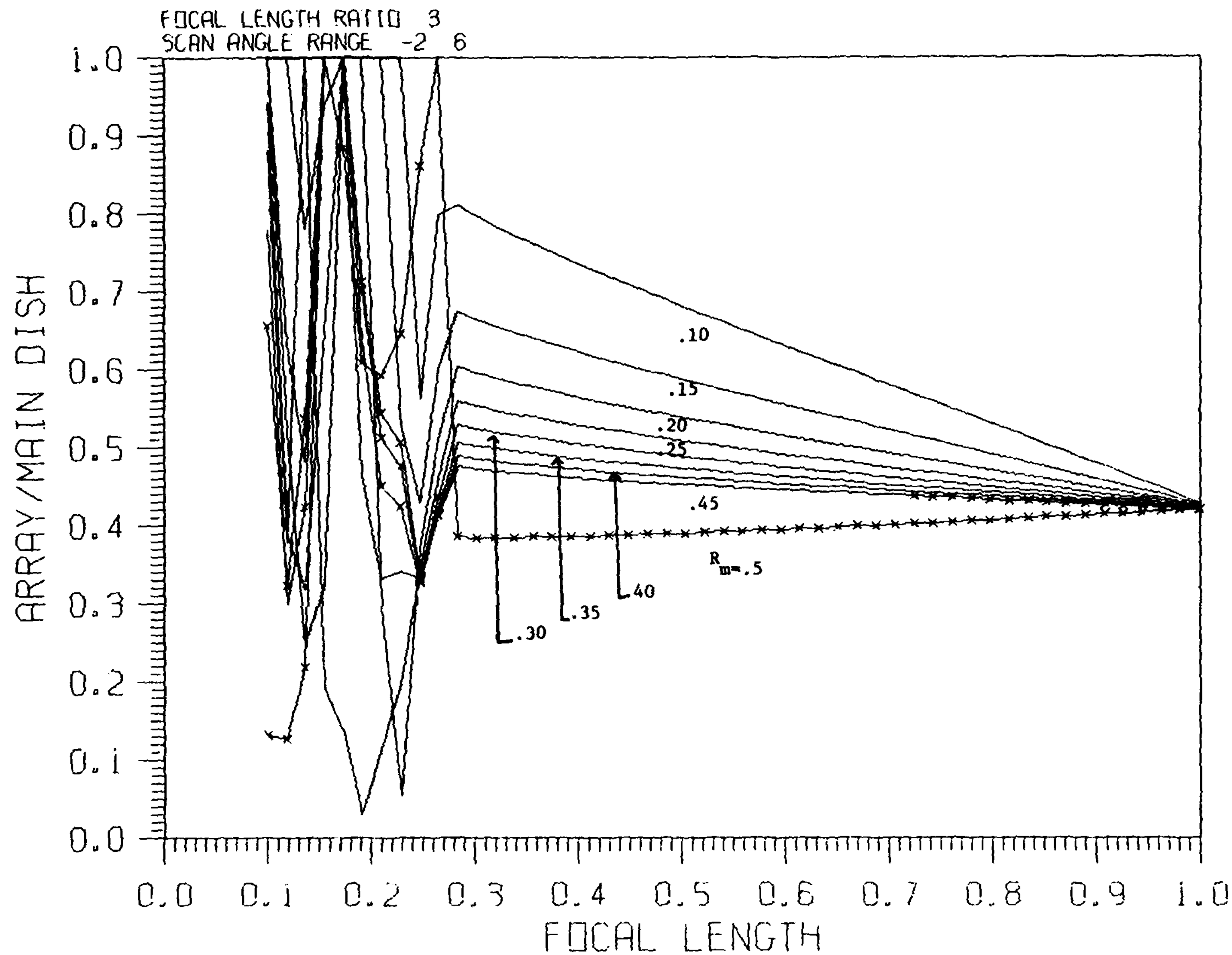


Fig. 10c - Ratio of required array size to main dish vs. main dish focal length
R_m = normalized main dish size

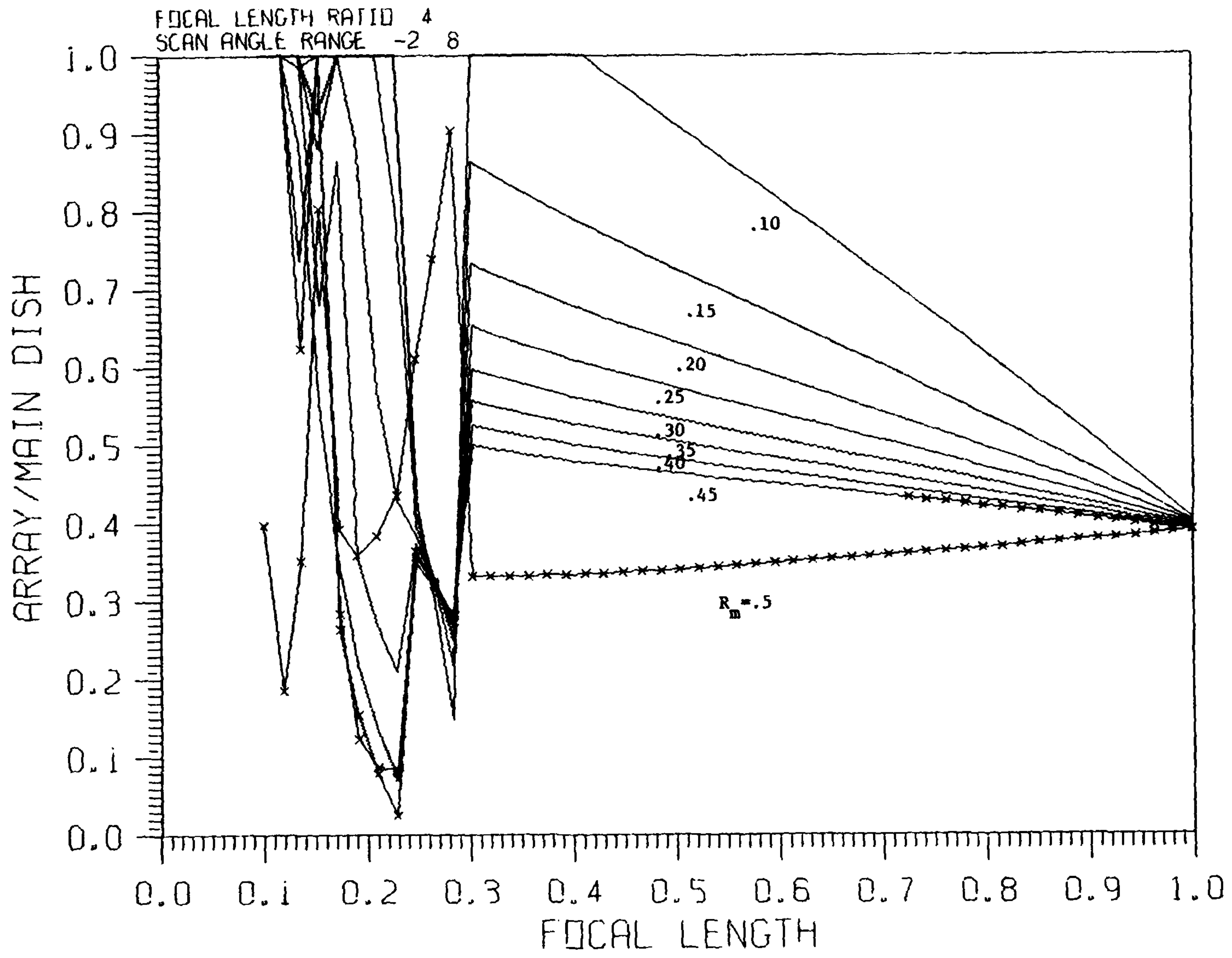


Fig. 11a - Ratio of required array size to main dish vs. main dish focal length
R_m = normalized main dish size

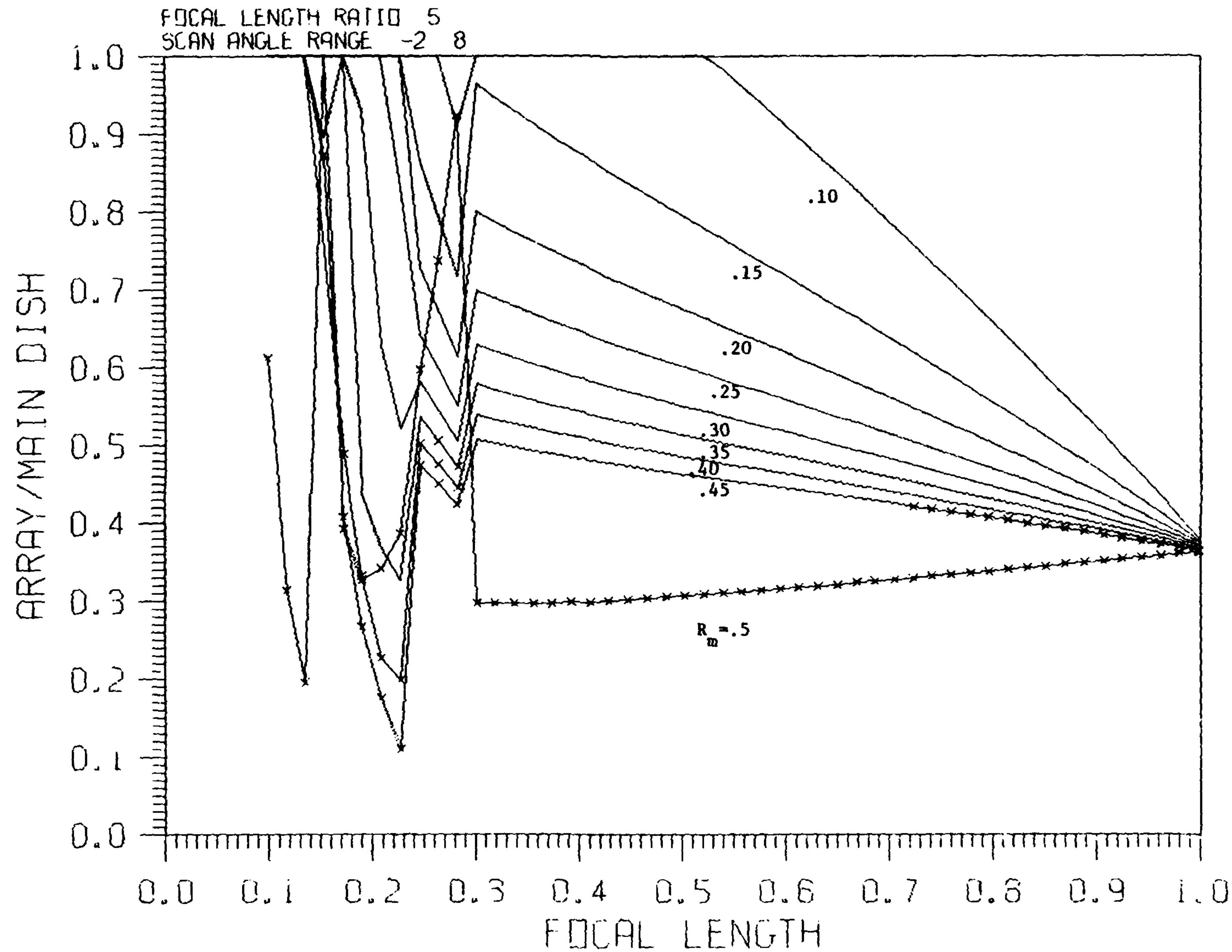


Fig. 11b - Ratio of required array size to main dish vs. main dish focal length
R_m = normalized main dish size

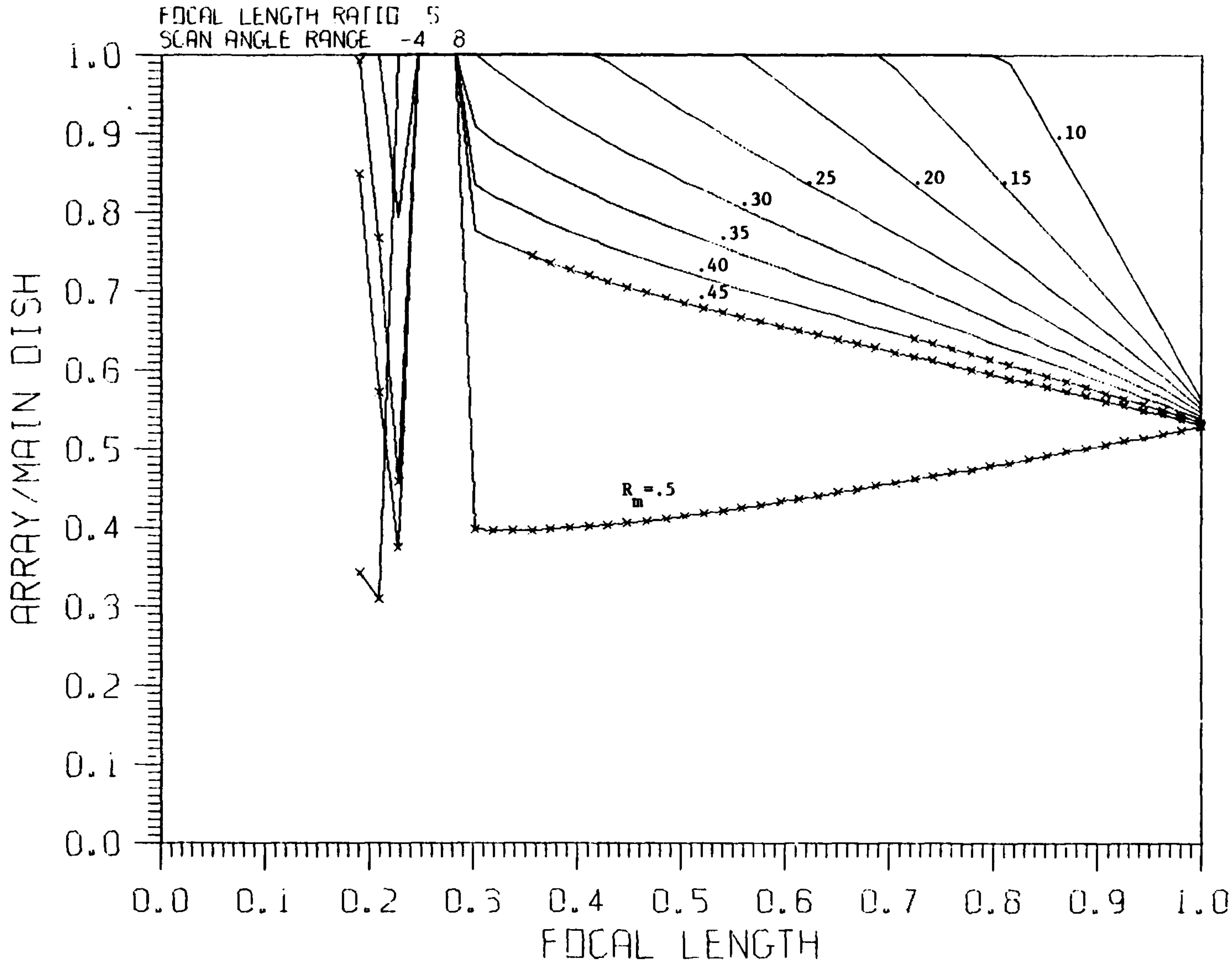


Fig. 12a - Ratio of required array size to main dish vs. main dish focal length
R_m = normalized main dish size

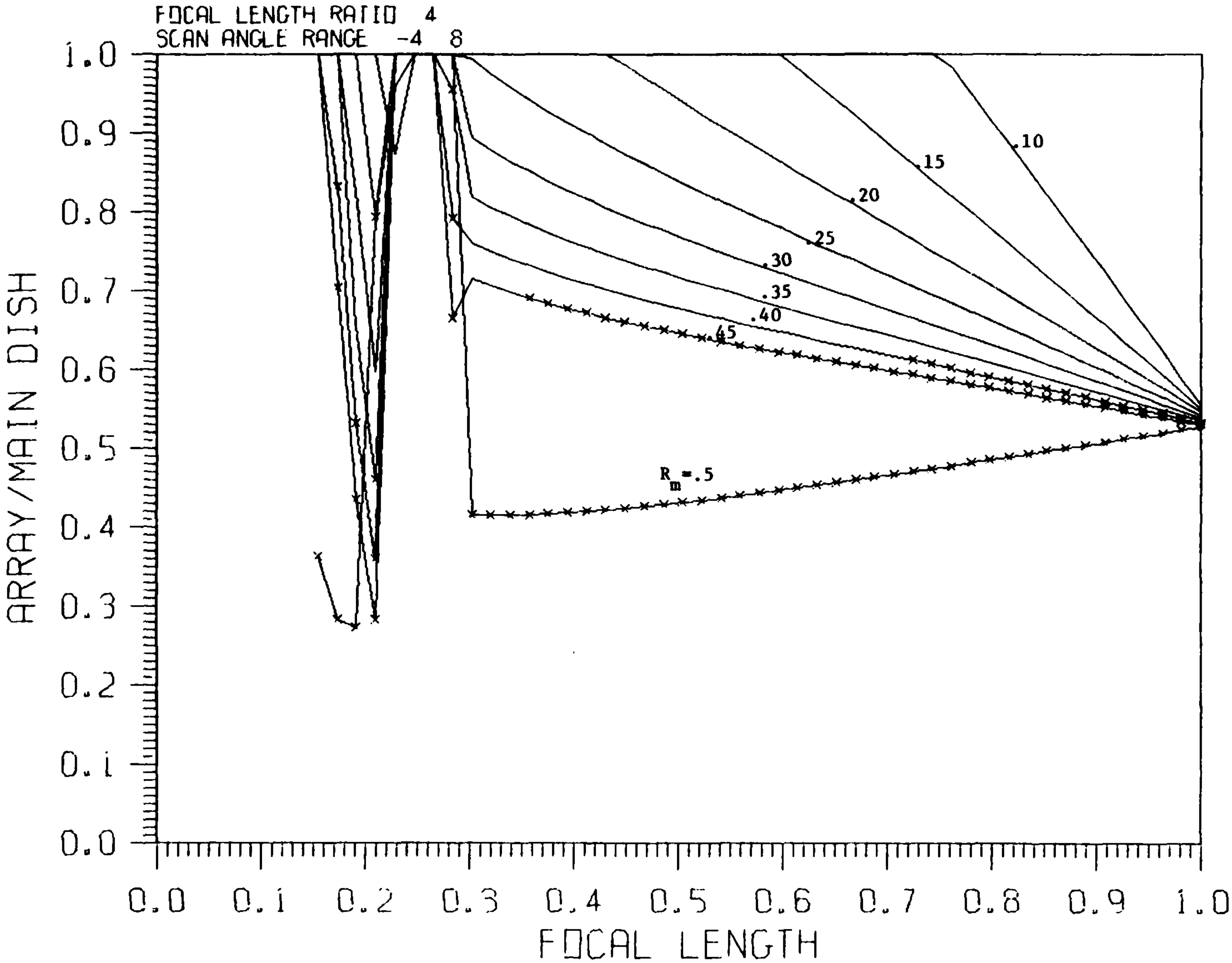


Fig. 12b - Ratio of required array size to main dish vs. main dish focal length
R_m = normalized main dish size

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